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TECHNICAL EVALUATION OF A RADON DAUGHTER CONTINUOUS MONITOR IN AN UNDERGROUND URANIUM MINE

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TECHNICAL EVALUATION OF A RADON DAUGHTER CONTINUOUS MONITOR IN AN UNDERGROUND URANIUM MINE

by

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ABSTRACT

An evaluation of a radon daughter monitor was carried out in an underground uranium mine. The monitor operates on continuous sampling and time integrating principles. Experimental and theoretical data were compared. Experimental results show that the monitor underestimates the Working Level, a fact which is partly attributed to plate-out of decay products in the monitor sampling head. However, a correction factor experimentally determined by standard calibration procedures can be programmed into the monitor to take into account losses by plate-out and other losses. Although the monitor was originally designed for radon daughters, it can equally be used in thoron daughter atmospheres and radon daughter/thoron daughter mixtures such as those encountered in some Canadian uranium mines. An analytical procedure is outlined to allow the calculation of Working Levels in radon daughter/thoron daughter atmospheres from the monitor α-count rate. The memory capability of the monitor should make it quite useful and flexible in underground and surface environments in the uranium mining industry.

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CONTENTS

	Page
ABSTRACT	i
INTRODUCTION	1
DESCRIPTION OF THE APPARATUS	1
EXPERIMENTAL PROCEDURE	4
ANALYTICAL PROCEDURE	5
EXPERIMENTAL RESULTS AND DISCUSSION	9
CONCLUSIONS	19
ACKNOWLEDGEMENT	20
REFERENCES	20

FIGURES

No.		
1a.	WL(Rn) and WL(Tn) versus time for 5 day-shifts. Also shown are the daily average values $\overline{WL}$(Rn) and $\overline{WL}$(Tn)	10
1b.	WL(Tn)/WL(Rn) for 5 day-shifts. Also shown is the average value for this ratio for the duration of the tests	10
2.	WL versus time for two different tests, as determined by the WLM-300. Also indicated are the time of underground blasting	11
3.	WL versus time according to the WLM-300 and grab-sampling	12
4.	Alpha-particle count rate versus time for the WLM-300 and theoretical	14
5.	Alpha-particle count rate versus time for the WLM-300 and theoretical	15

TABLES

1.	Summary of radiation data corresponding to 5-shifts of underground testing	6
2.	Summary of some meteorological data (daily average) obtained during 5 day-shifts of underground testing	7

INTRODUCTION

Adequate mine air quality control is attained by monitoring radiation levels. Proper radiation monitoring and control prevents unnecessary risk to occupational workers.

Radiation monitoring is essentially of two kinds: discrete sampling, i.e., grab-sampling, and continuous sampling. The advantages and disadvantages of these two methods for determining the short-lived decay products of radon and thoron in uranium mines have been discussed in detail by Bigu (1).

In spite of the recent proliferation of radiation instrumentation for estimating radon and thoron decay products, there is a need for an automated area monitoring instrument with memory storage capabilities suitable for unattended monitoring for extended periods of time. Such an instrument could be used extensively in underground environments for air quality monitoring purposes. An instrument of this kind, operating on time integrating principles, is available and has been tested in an underground uranium mine in the Elliot Lake area. This report presents data pertaining to a technical evaluation of this instrument and is a continuation of previous work carried out with the same instrument tested under controlled laboratory conditions in a radon/thoron calibration facility (2). The instrument has been described in detail elsewhere (2), but will be described here again for completeness. The instrument has been designed and built by EDA Instruments (Toronto) and is commercially available under the name WLM-300.

DESCRIPTION OF THE APPARATUS

The EDA WLM-300 basically consists of a sampling-detection system, a memory unit to store data, and read-out and print-out capabilities. The instrument operates by sampling air in a continuous fashion. Decay products

are deposited on a sampling filter facing the detector and the α-count is integrated in a manner described below. The instrument is claimed to be dust-proof, moisture-proof and shock-proof.

The detection-sampling 'head' consists of a sample holder housing a filter (Millipore 0.8 μm AA) supported by a fine stainless steel mesh screen. A ruggedized silicon-barrier detector (450 mm^2 active area) faces the active side of the filter. The detector-filter separation is about 3.2 mm, according to the manufacturer's specifications.

The front-end electronics of the detector has a voltage threshold corresponding to an α-energy of about 2 MeV to eliminate contributions from electronic noise and β-radiation. α-particles in the 2 MeV to 10 MeV energy range are in principle detected and counted. Although the apparatus has no pulse height analysis capabilities, it is provided with an output jack to enable interfacing with an external multi-channel analyzer (MCA) for pulse height analysis.

The filter-detector holder is cylindrically shaped and is made of a plastic material (Teflon) consisting of an upper and a lower part. In the normal operating mode, the upper part is fitted, leak-free by means of a rubber gasket, to the lower part by screwing the former into the latter. The upper part has exhaust holes leading to the inlet of a small self-regulated sampling pump (1 L/min) which draws air in and passes it through the sampling filter facing the detector. The lower part has a circular inset where the detector is located. Four inlet slits of rectangular cross-section (15 mm x 2 mm) and 30 mm length are radially and symmetrically oriented permitting air to be sampled to pass the detector through a filter facing the detector. The detector is located in a recess, about 1 mm below the slits.

The detection-sampling head is located in a re-entrant 'cavity' built on one side of the instrument case. The inlet access slits, detector and

sampling filter are located at an approximate depth of 38 mm from the surface of the case.

The instrument has a liquid crystal display (LCD) which displays the α-count rate internally obtained by dividing the total number of α-counts by the total sampling time, and the WL obtained from the above α-count rate and a given numerical conversion factor.

A memory unit enables data storage which can be later retrieved by an external printer. Data are gathered every 6 min or 60 min. The memory capacity is of 4.1 days if data are gathered every 6 min, or 41 days if data are gathered every 60 min.

The data stored can be retrieved in the following forms:

a) As differential α-count at any given time. This is the α-count obtained by subtracting the total α-count stored up to the last (previous) count, from the total α-count up to this time;

b) As total α-count. This is the total, accumulated, α-count up to the time data are retrieved;

c) As differential WL. This is calculated from item (a) and a given numerical conversion factor; and

d) As a time integrated WL which is calculated from the integral, total α-count obtained, the total counting time, and the same conversion factor as that indicated (see above and item (c)).

For simplicity the WLM-300 will be referred to hereafter as the monitor.

EXPERIMENTAL PROCEDURE

The monitor has been previously tested under laboratory controlled conditions. Measurements were conducted with 'pure' radon daughter atmospheres or 'pure' thoron daughter atmospheres, but not with radon daughter/thoron daughter mixtures. Because some uranium mines have Th-232, and hence thoron gas, in appreciable amounts it was of interest to test the instrument in mine atmospheres with variable radon/thoron mixtures. In addition, it was also of interest to investigate the response of the instrument to sudden, large, increases in radiation level such as those produced in blasting operations.

The monitor was taken underground in an area situated at the exhaust of several working stopes in an uranium mine. The instrument was operated continuously for a number of day-, evening- and night-shifts. Concurrent measurements of several radiation variables of interest were carried out during the day-shifts. Furthermore, radioactive aerosol and dust studies as well as barometric pressure, temperature and relative humidity measurements were conducted.

Radon daughter (RaA, RaB and RaC concentrations and Working Level, WL(Rn), were determined by the Thomas-Tsivoglou method (3,4). WL(Rn) measurements were also done using the Markov and Kusnetz methods (5,6,7).

Thoron daughter (ThB and ThC) concentrations and Working Level, WL(Tn), were determined by an α-spectroscopy method (8). ThB concentration and WL(Tn) were also estimated by a single gross α-count technique similar to the Kusnetz method (9).

Radiation measurements were made about 30 min apart on the average during the normal day-shift. Meteorological variables were measured every

20 min. During the underground testing, four scheduled blastings occurred, and several mining operations took place at an adjacent stope where the air exhaust was monitored by the WLM-300 and other radiation instrumentation. Some radiation and meteorological data obtained by grab-sampling during the underground evaluation of the monitor have been summarized in Tables 1 and 2, where daily averages of several radiation variables of interest are given.

ANALYTICAL PROCEDURE

Experimental data obtained with the monitor were compared with theoretical results following analytical procedures described elsewhere (2,10). Experimental and theoretical α-count rates versus sampling time were compared.

A simple relationship between α-count rate and WL, say C_F, can be defined as follows:

$$C_F = \alpha\text{-count rate/WL} \qquad \text{Eq 1}$$

The definition of C_F in Equation 1 assumes WL and the sampling flow rate to remain constant throughout the sampling period. The above expression is equally applicable to experimental and theoretical cases.

Because of the working physical principle of the monitor, i.e., continuous sampling and hence time integration of the α-count, the α-count and C_F are time dependent until a 'steady-state' is reached. The steady-state is attained when the rate of growth of decay products accumulated in the filter under continuous sampling equals their rate of radioactive decay. As with C_F, the definition of 'steady-state' assumes the sampling flow rate and the airborne decay product concentrations, and hence WL, to remain constant during the sampling period. The value of C_F under steady-state conditions is denoted as $C_{F,SS}$.

As the monitor does not differentiate α-particles from radon daughters

Table 1 - Summary of radiation data corresponding to 5-shifts of underground testing

Date	WL(Rn)	WL(Tn)	$\frac{WL(Tn)}{WL(Rn)}$	[RaA] (Bq/L)	[RaB] (Bq/L)	[RaC] (Bq/L)	[ThB] (Bq/L)	[ThC] (Bq/L)	1:X:Y*	$\frac{[ThC]}{[ThB]}$
April 30	0.49±0.03	0.41±0.02	0.83±0.1	2.89±0.44	1.93±0.19	1.46±0.07	0.086±0.005	0.041±0.006	1:0.67:0.5	0.47
May 4	0.45±0.03	0.39±0.02	0.87±0.07	3.01±0.44	1.77±0.15	1.28±0.10	-	-	1:0.59:0.42	-
May 5	0.43±0.03	0.43±0.02	0.98±0.13	2.97±0.33	1.71±0.14	1.19±0.16	0.088±0.032	0.037±0.005	1:0.58:0.40	0.42
May 6	0.46±0.02	0.41±0.03	0.88±0.05	3.04±0.13	1.80±0.13	1.30±0.13	0.087±0.01	0.040±0.01	1:0.59:0.43	0.28
May 7	0.49±0.02	0.43±0.01	0.87±0.04	3.22±0.42	1.91±0.10	1.39±0.11	0.125	0.032	1:0.59:0.43	0.25

* 1 = [RaA]/[RaA] ; X = [RaB]/[RaA] ; Y = [RaC]/[RaA]

Table 2 - Summary of some meteorological data (daily average) obtained during 5 day-shifts of underground testing

Date	Temperature [°C]	Barometric Pressure [kPa]	Relative Humidity %
April 3	18.75±1.77	107.02±0.13	-
May 4	16.11±0.25	106.84±0.07	82.67±0.44
May 5	16.46±0.73	106.35±0.07	83
May 6	16.21±0.37	105.38±0.11	89
May 7	16.76±0.21	105.05±0.04	90

from α-particles from thoron daughters, one may define two C_F factors, one for radon daughters and one for thoron daughters. Thus:

$$C_F\ (Rn)_{th} = cpm(Rn)/WL(Rn)_{th} \qquad \text{Eq 2}$$

and,

$$C_F\ (Tn)_{th} = cpm(Tn)/WL(Tn)_{th} \qquad \text{Eq 3}$$

where, in Equations 2 and 3 the symbols Rn and Tn in round brackets refer to radon daughters and thoron daughters, respectively. The subindex 'th' indicates theoretical. The theoretical α-count rate is denoted by cpm. Equations 2 and 3 assume a counting efficiency of the detector, for α-particles, say ε, of unity.

The total, theoretical, α-count rate for a radon daughter/thoron daughter mixture can be calculated using Equations 2 and 3 as follows:

$$cpm(total) = cpm(Rn) + cpm(Tn) = cpm(Rn + Tn)$$

$$= WL(Rn)_{th}\ C_F(Rn)_{th} + WL(Tn)_{th}\ C_F(Tn)_{th} \qquad \text{Eq 4}$$

Equations 2, 3 and 4 assume 100% collection efficiency of the filter to decay products, no plate-out of decay products in the sampling head of the monitor and that no appreciable absorption of α-particles in the filter takes place.

Experimental total α-count rate, CPM(total), obtained with the monitor was compared with the theoretical total α-count rate, cpm(total), calculated from theoretical values of the C_F-factors (i.e., $C_F(Rn)_{th}$ and $C_F(Tn)_{th}$, see references 2 and 3) and experimental values for the daily averages of the radon and thoron daughters concentrations and the radon (thoron) daughter WLs as determined by grab-sampling (see Table 1).

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1 shows WL(Rn) and WL(Tn) by grab-sampling versus time for 5 day-shifts, and the daily average values for the same variables. Also shown is the daily-averaged ratio WL(Tn)/WL(Rn) for the above 5 day-shifts. Figure 1 indicates that WL(Rn) and WL(Tn) remained reasonably constant during the tests with a maximum variation of approximately ±12% about the mean daily average. A maximum variation of approximately ±10% about the weekly average for the ratio WL(Tn)/WL(Rn) was observed.

Figure 2 shows the WL as determined by the monitor for two 24 hr periods of continuous operation. Also shown are the times at which blasting operations took place.

Figure 3 shows the WL as determined by the monitor for 3 day-shifts Also shown are WL(Rn), WL(Tn) and WL(Rn) + WL(Tn) by grab sampling as a function of time for each shift. A significant discrepancy between grab-sampling data and the results obtained with the monitor is observed. Assuming for the purpose of illustration that the monitor only responded to radon daughters, comparison of WL(Rn) by grab-sampling and the WL indicated by the monitor shows that the latter underestimates WL(Rn) by approximately 30-40%, a fact which is consistent with previous data obtained under laboratory controlled conditions in a radon box (2). The discrepancy is even higher when WL(Rn) + WL(Tn) by grab-sampling is compared with the WL indicated by the monitor. However, this discrepancy is more apparent than real as the instruments raw data is acquired as α-count or α-count rate and then converted to WL electronically by assuming a conversion factor for radon daughters. Since the monitor has no internal α-spectroscopy capabilities, it cannot differentiate radon daughters from thoron daughters and the conversion factor used is, therefore, not correct for radon daughter/thoron daughter mixtures.

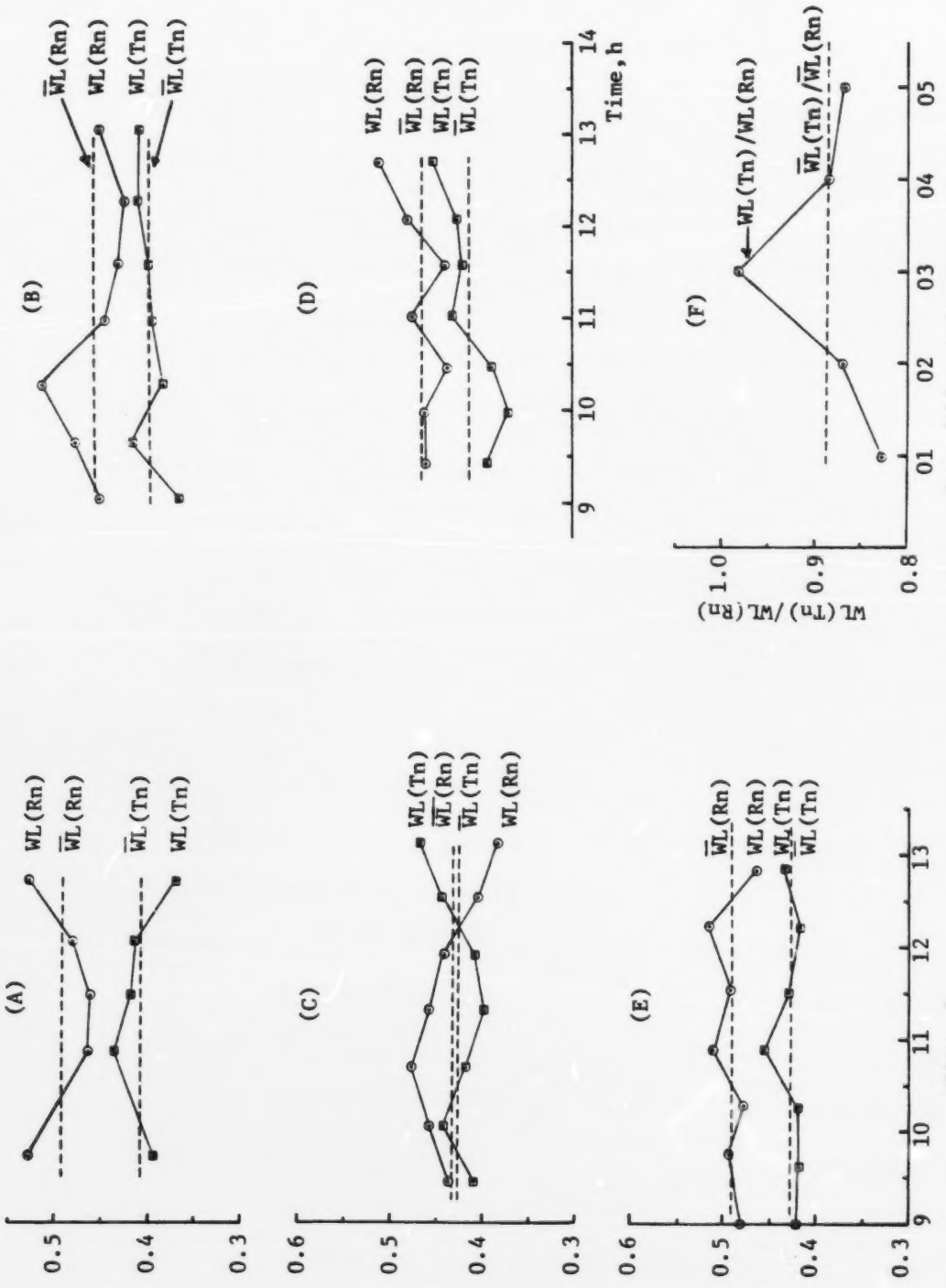
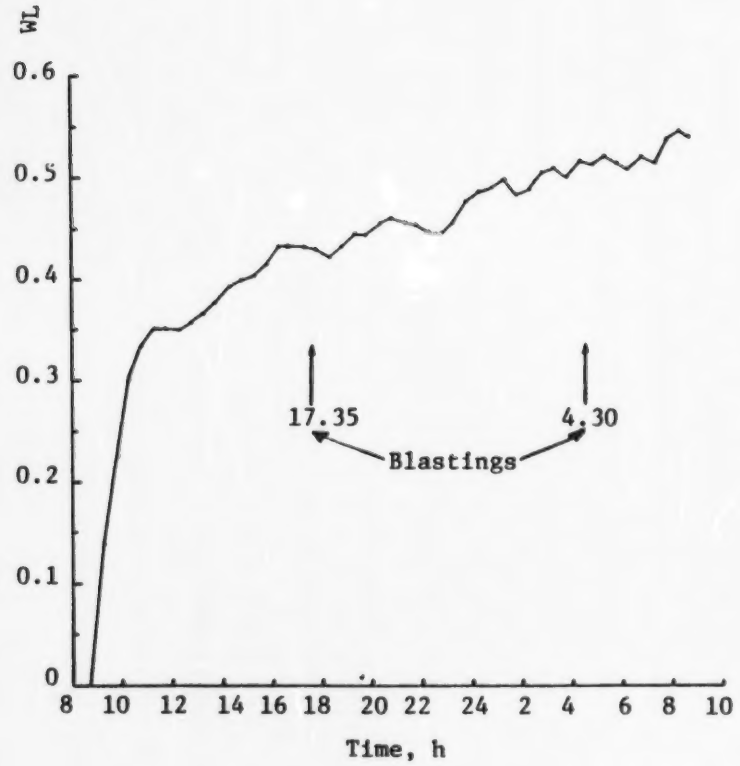


Fig. 1 - (a) WL(Rn) and WL(Tn) versus time for 5 day-shifts (graphs A to E). Also shown in the graphs are the daily average values $\overline{WL}$(Rn) and $\overline{WL}$(Tn), indicated by broken lines.
(b) WL(Tn)/WL(Rn) for 5 day-shifts (graph F). Also shown in broken lines is the average value for this ratio for the duration of the tests.



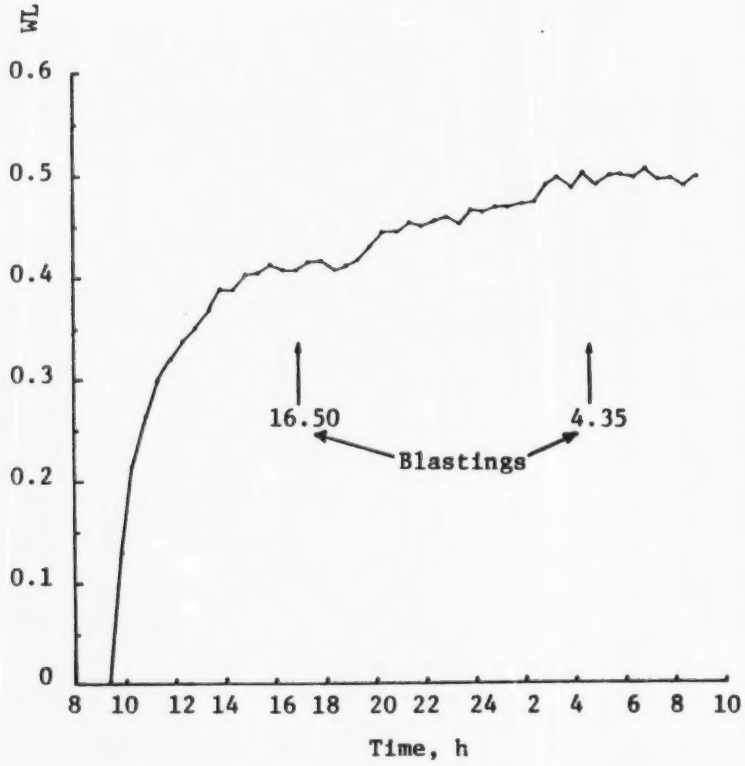


Fig. 2 - WL versus time for two different tests, as determined by the WLM-300. Also indicated by vertical arrows are the time of underground blasting.

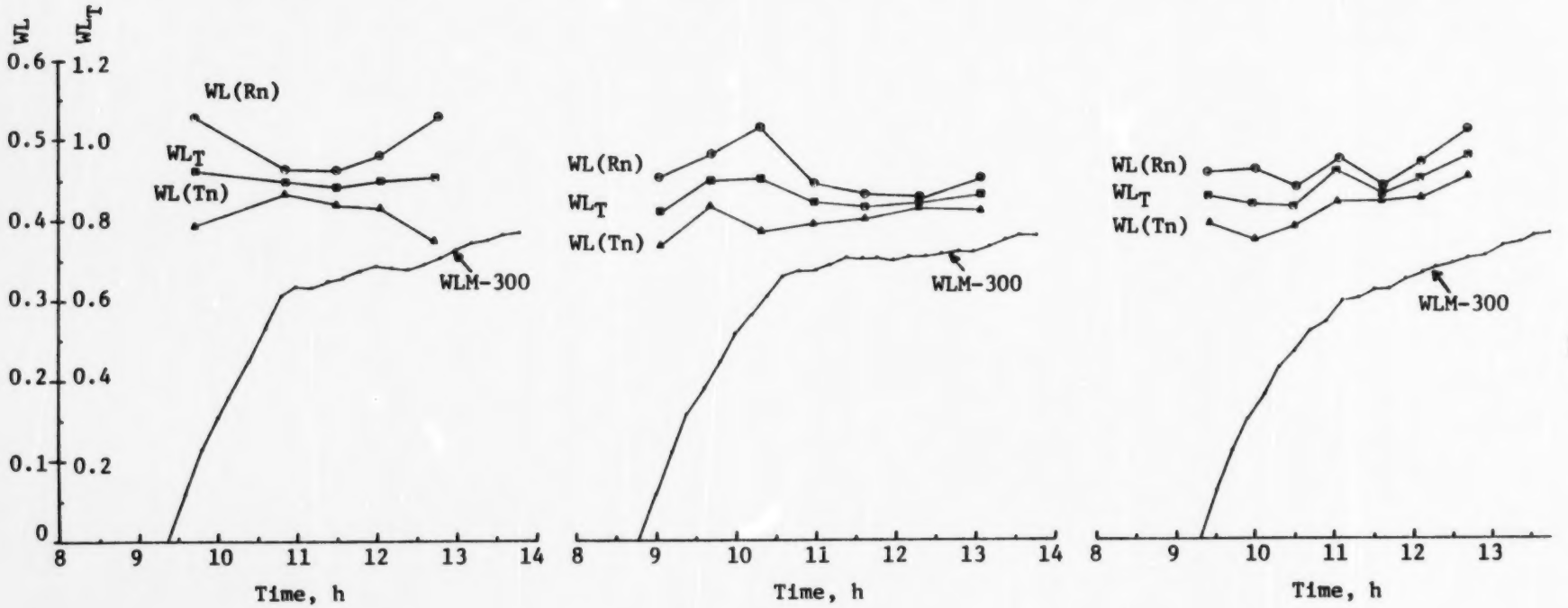


Fig. 3 - WL versus time according to the WLM-300 (-•-•-) and grab-sampling: WL(Rn) (-●-●), WL_T(-■-) and WL(Tn) (-▲). WL_T stands for total WL, i.e. WL(Rn) + WL(Tn).

When use is made of α-count or α-count rate instead of WL, the agreement between grab-sampling and the monitor is considerably improved as it can be seen in Fig. 4, 5 and 6. These Figures show the experimentally determined α-count rate by the monitor and the calculated cpm(Rn), cpm(Tn) and cpm(RN+Tn) for 3 days of underground testing (see Equations 2, 3 and 4).

The seemingly better agreement between experimental and theoretical data shown in Fig. 4, 5 and 6 as compared with Fig. 3 can be understood on the basis of the definition of the Working Level. It is easily shown that the α-count contribution corresponding to WL(Tn) is only a fraction of that of WL(Rn) for comparable values of both WL(Rn) and WL(Tn). It should be borne in mind, however, that this is only true for sampling times not much longer than about 3 hr after which the radon daughter activity on the monitors filter reaches a steady-state whereas the thoron daughter activity continues to grow for considerably longer periods of time before reaching steady-state conditions. This is illustrated in Fig. 4, 5 and 6 where the contribution from thoron daughters to the total cpm can be calculated to be about 10%, 15% and over 35% for sampling times of 180 min, 300 min and over 1000 min, respectively.

Figures 4, 5 and 6 also show that in qualitative terms, the theoretical cpm(Rn+Tn) and the experimental total α-count rate by the monitor are in good agreement although the latter is lower by about 30-40%, an observation which agrees, as indicated above, with previous work and which was partly ascribed to plate-out of decay products in the sampling head (2). It should be noted that a precise comparison of theoretical and experimental data is difficult because underground radiation levels did not remain constant during the test, although they did not vary dramatically, i.e., within ±12% about the mean daily average

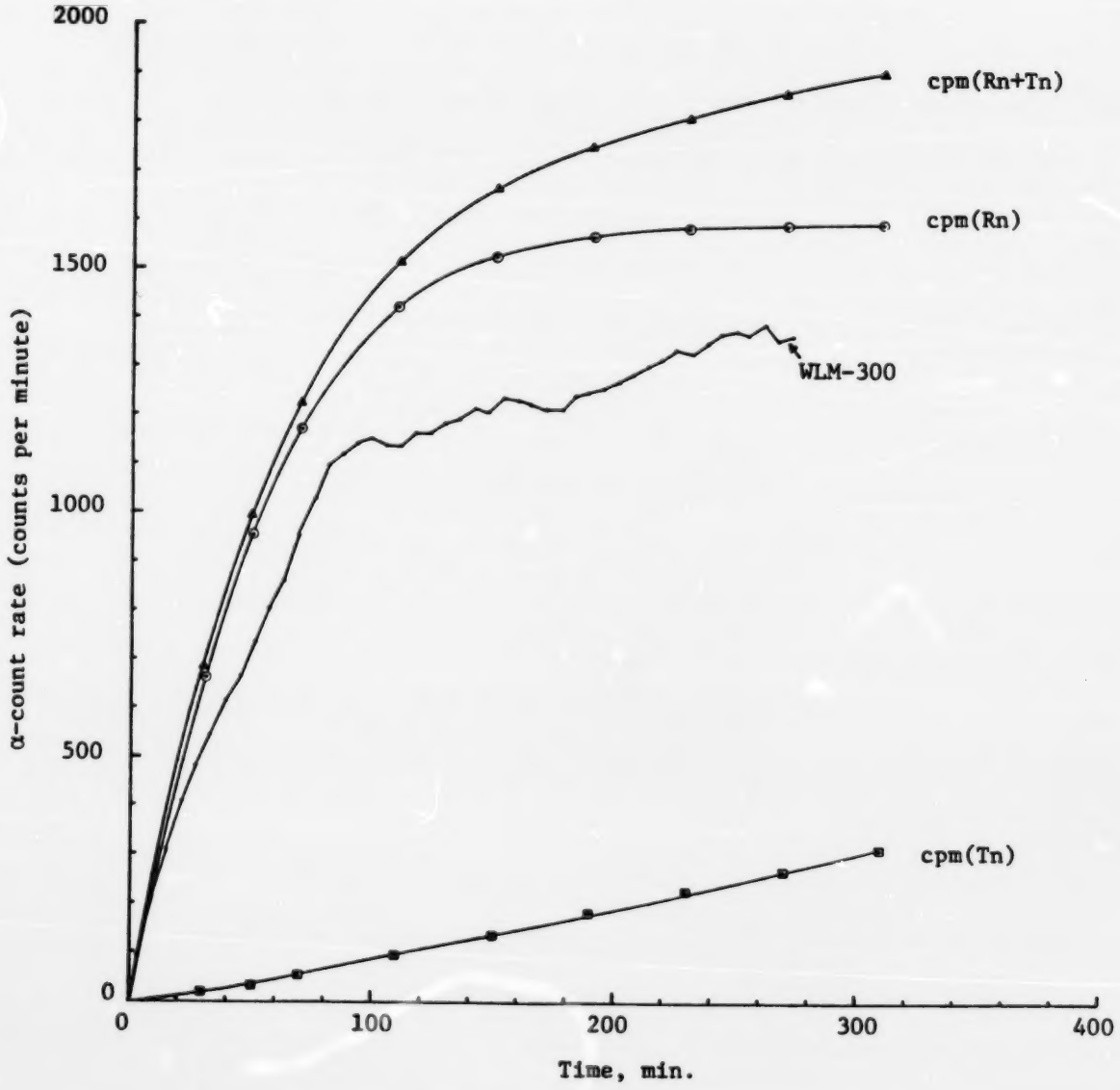


Fig. 4 - Alpha-particle count rate versus time (a) for the WLM-300(-·-) and (b) theoretical: cpm(Rn) (-●-), cpm(Tn) (-■-) and total (-▲-). Note that the theoretical cpm has been calculated from experimental data for WL and the CF-factors as indicated in the text, i.e. cpm(Rn) = WL(Rn) CF(Rn), cpm(Tn) = WL(Tn) CF(Tn) and cpm(Rn+Tn) = cpm(Rn) + cpm(Tn).

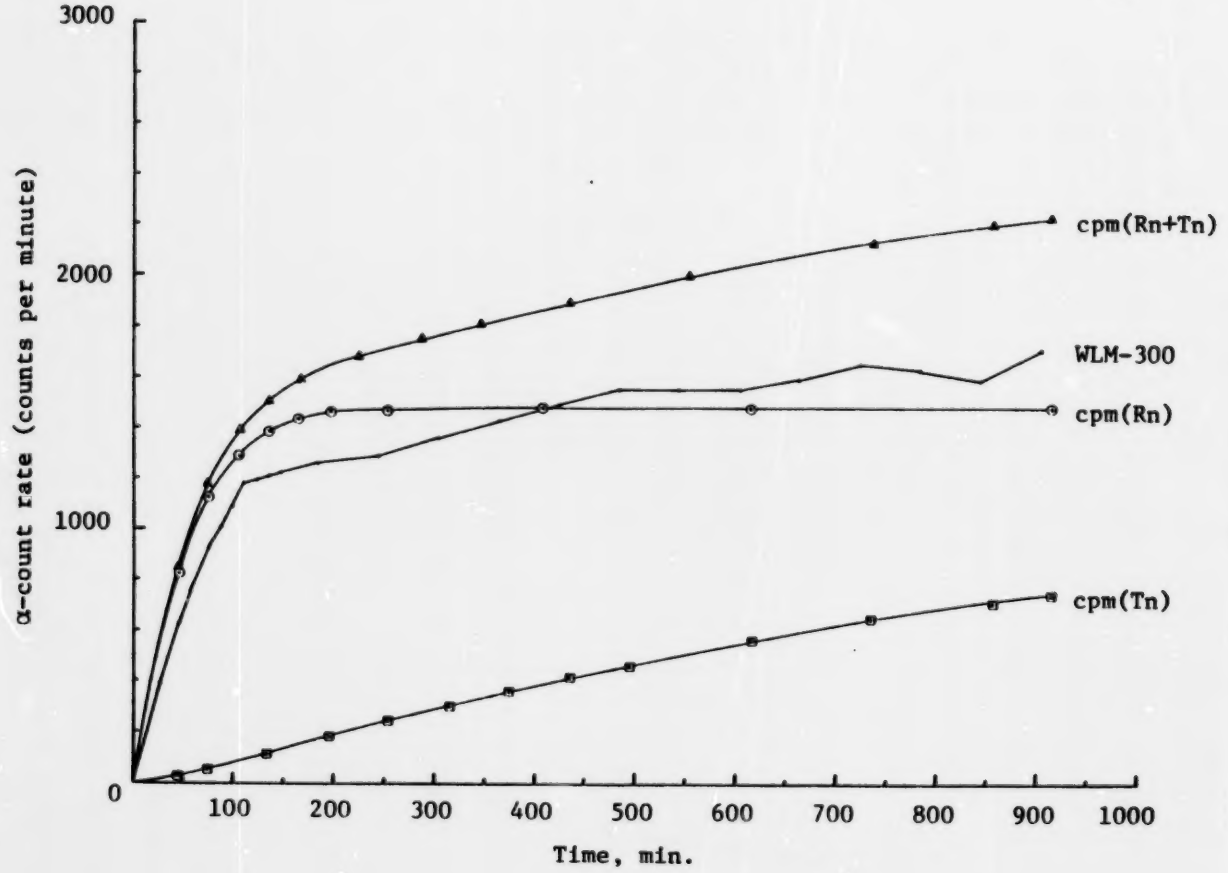


Fig. 5 - Alpha-particle count rate versus time (a) for the WLM-300 (-•-) and (b) theoretical: cpm(Rn) (-●-), cpm(Tn) (-■-) and total (-▲-). Notice that the theoretical cpm has been calculated from experimental data for WL and the CF-factors as indicated in the text, i.e. cpm(Rn) = WL(Rn) CF(Rn), cpm(Tn) = WL(Tn) CF(Tn) and cpm(Rn+Tn) = cpm(Rn) + cpm(Tn).

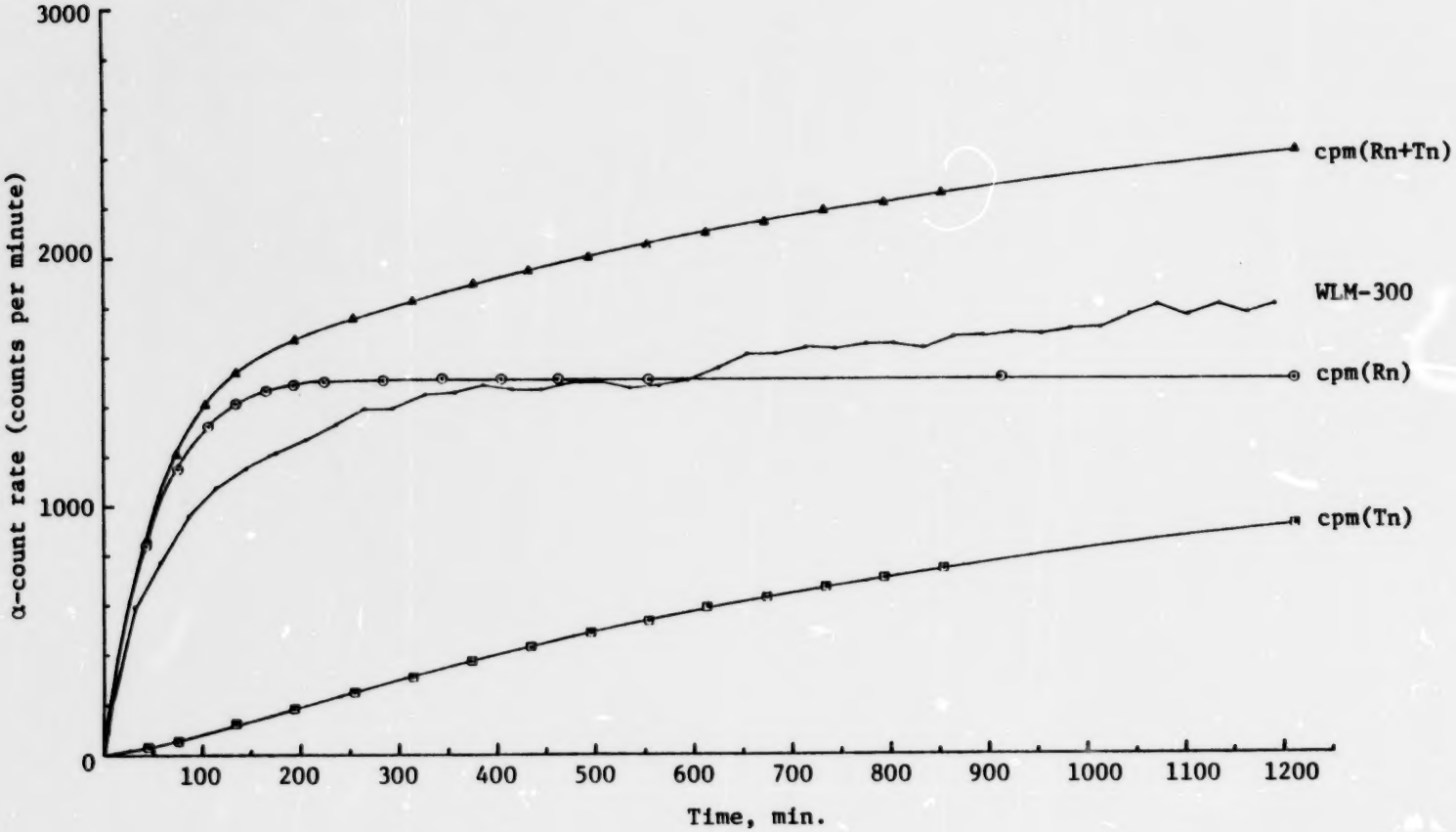


Fig. 6 - Alpha-particle count rate versus time (a) for the WLM-300 (-•-) and (b) theoretical: cpm(Rn) (-●-), cpm(Tn) (-■-) and total (-▲-). Notice that the theoretical cpm has been calculated from experimental data for WL and the CF-factors as indicated in the text, i.e. cpm(Rn) = WL(Rn) CF(Rn), cpm(Tn) = WL(Tn) CF(Tn) and cpm(Rn+Tn) = cpm(Rn) + cpm(Tn).

(see Table 1 and Fig. 1).

The monitor did not seem to respond appreciably to the increase in radiation level brought about by blasting. This is not surprising because of the 'long time constant' associated with instruments operating on time integrating principles and the relatively long half-lives of the decay products collected in the monitors' filter. The combination of these two factors makes the monitor predictably slow to respond to sudden changes in radiation levels. However, the virtual absence of response of the monitor to the blasting operations also seems to indicate other contributing factors, namely:

a) The radiation contribution from the blasting was small compared to the 'background' WL before the blasting;

b) The blasting contribution was comparable to the usual WL fluctuations caused by ventilation changes and other factors, as illustrated by grab-sampling and monitor measurements (see Fig. 1 and 3).

Items (a) and (b) might be related to the fact that for practical reasons, and to prevent damage, the monitor was located relatively far from the blasting sites. Hence, it is possible that the effect of the blasting had sensibly weakened at the monitors location. As no radiation data during and immediately before and after the blasting are available for comparison purposes other than that collected by the monitor, we have no way to confirm the above assumptions and more experimental work will be needed.

From the above discussion and previous data one may conclude that the monitor appreciably underestimates WL and that no distinction is made between the contribution to the total WL by radon daughters and thoron daughters. However, experimental data provided by the monitor can be corrected to take into account plate-out of decay products in the sampling head and

other sources of error. This can be done simply by using the following expressions:

$$CPM(Rn)\ F(Rn) = C_{F,SS}(Rn)_{th}\ WL(Rn)\ \varepsilon \qquad \text{Eq 5}$$

$$CPM(Tn)\ F(Tn) = C_{F,SS}(Tn)_{th}\ WL(Tn)\ \varepsilon \qquad \text{Eq 6}$$

where Equations 5 and 6 are only applicable to radon daughters and thoron daughters, respectively. WL(Rn) and WL(Tn) are the true experimental radon daughter and thoron daughter WLs, respectively. CPM(Rn) and CPM(Tn) are the experimental α-count rates for radon daughters and thoron daughters given by the monitor, respectively. $C_{F,SS}(Rn)_{th}$ and $C_{F,SS}(Tn)_{th}$ are the theoretical factors defined by Equation 1 under steady-state conditions for radon daughters and thoron daughters, respectively. The factor F (>1) in Equations 5 and 6 is included to take into account plate-out and other losses of decay products in the monitor. In general F can be defined by:

$$F(i) = \delta'(i)\ \eta'(i) \qquad \text{Eq 7}$$

where, i in Equation 7 refers to radon daughters, Rn, or thoron daughters, Tn. The coefficients δ', η' take into account plate-out of decay products in the sampling head and absorption of α-particles in the sampling filter, respectively. ε in Equations 5 and 6 is the α-counting efficiency of the detector, which for simplicity is assumed to be the same for radon daughters and thoron daughters.

Assuming $F(Rn) \simeq F(Tn) = F$, it can be shown from Equations 5 and 6 that:

$$WL(Rn) = \frac{CPM(total)(F/\varepsilon)}{C_{F,SS}(Rn)_{th} + C_{F,SS}(Tn)_{th}\ WLR} \qquad \text{Eq 8}$$

where,

$$WLR = WL(Tn)/WL(Rn), \text{ and} \qquad \text{Eq 9}$$

$$CPM(total) = CPM(Rn) + CPM(Tn). \qquad \text{Eq 10}$$

From the experimental data presented here and previous data (2), values for F(Rn) can be obtained. For high aerosol and dust concentration,

$N\ cm^{-3}$, $F(Rn) \simeq 1.3$. For low aerosol concentration $F(Rn) \simeq 1.5$. These values are only approximate. More accurate values can easily be calculated from data previously presented and data in this report. (Note: high aerosol concentrations are defined here as those atmospheres for which $N \geq 10^4\ cm^{-3}$.)

Equation 8 shows that WL(Rn) can be obtained from the experimental α-count rate given by the monitor if WLR is known and F is obtained by standard calibration procedures. As $C_{F,SS}(Tn)_{th} \simeq 0.5\ C_{F,SS}(Rn)_{th}$ (10), only relatively large variations of WLR affect WL(Rn) appreciably. Measurements over the last 3 years in some Canadian mines show that most values of WLR are between 0.5 and 1.2 with a maximum at about 0.6 (11). In the present series of tests WLR ≃ 0.88 (see Table 1).

WL(Tn) can be calculated from the experimental value for WL(Rn) obtained by the monitor using Equation 8 and WLR (see Equation 9).

CONCLUSIONS

The data discussed in this report and in a previous study (2) show that the monitor appreciably underestimates WL by an amount which depends on the aerosol concentration. This behaviour is partly ascribed to plate-out of decay products in the sampling head. However, calibration of the instrument will compensate for plate-out losses by introducing an adequate correction factor. Although the monitor was originally designed for radon daughters, it can also be used for thoron daughters and radon daughter/thoron daughter mixtures such as those encountered in some Canadian underground uranium mines. This is possible by modifying the conversion factor used by the monitor, set at the factory, by adequate calibration procedures.

Because of the physical principle on which the monitor is based, its response to fast changes in radiation levels is limited showing a time-lag for radon daughters of about 1 hr. Furthermore, a minimum sampling time, under

constant conditions, of about 2.5 hr for radon daughters and over 10 hr for thoron daughters is necessary before reliable information can be gained. The above minimum sampling times being those necessary for a radioactive 'steady-state' or equilibrium condition in the sampling filter to be reached. This subject is discussed in detail elsewhere (2).

The WLM-300 should prove a quite flexible and useful instrument for monitoring underground and surface environments in the uranium mining industry. The memory capabilities of the instrument are particularly noteworthy and its flexibility ideally suitable for experimental and theoretical applications.

Recently, EDA has developed a new sampling head with much improved plate-out characteristics. Measurements conducted at the time of typing this report with the new sampling head give results which are in close agreement (within 10%) with those obtained by conventional, standard, grab-sampling using several methods.

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